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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of: David J. McElroy et al.
Title: REDUNDANT IMAGING METHODS AND SYSTEMS
Attorney Docket No.: 303.615US1

PATENT APPLICATION TRANSMITTAL

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UNITED STATES PATENT APPLICATION

REDUNDANT IMAGING METHODS AND SYSTEMS

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REDUNDANT IMAGING METHODS AND SYSTEMS

Technical Field

The present invention concerns imaging arrays and methods, particularly methods for correcting or compensating for defective or malfunctioning photodetectors in an imaging array.

Background of the Invention

Imaging arrays are electronic devices that sense light and output electrical signals representative of the sensed light. The imaging arrays are generally coupled to a television screen, computer monitor, or digital camera, which displays or records an image based on the output electrical signals.

An imaging array often includes a rectangular array or matrix of thousands or even millions of photodetectors, with each photodetector having a unique row and column position within the array which corresponds to a particular region, known as a pixel, of a displayed image. Each photodetector (or sensor pixel) converts sensed light into corresponding electric signals based on the intensity of the light. The electrical signals are converted into digital signals, comprising ones and zeros, which are processed by a digital-signal-processing circuit. This circuit ultimately outputs image signals to a device for recording or viewing.

One problem with conventional imaging arrays concerns defective or malfunctioning photodetectors. Defective photodetectors typically result in erroneous image signals that ultimately degrade the quality of resulting images. For example, an image based on imaging signals from an imaging array having a defective photodetector can have a black or dark area at the image region corresponding to the defective photodetector.

One limited solution to this problem has been to identify the defective photodetector and to generate a substitute image signal for the image signal of the defective photodetector, with the substitute image signal based on an average of the image signals from detectors surrounding it. See, for example, U.S. Patent

5,854,655 (which is incorporated herein by reference). However, this solution suffers from the disadvantage that the substitute image signal introduces artifacts into the resulting image. The artifacts reflect the complete loss of information about the light actually striking the relatively large area corresponding to the defective photodetector.

Accordingly, there is a need for other methods of handling defective photodetectors.

Summary of Invention

To address this and other problems, the present inventor devised new imaging arrays and related methods for compensating for defective photodetectors. One exemplary embodiment of a new imaging array includes two or more group photodetectors, or "group pixels," with each group pixel having two or more photodetectors coupled to produce a single group image signal. If the group image signal for a group pixel falls below some threshold level indicative of a defective or malfunctioning photodetector, the group image signal is amplified to compensate for the loss.

Various embodiments implement the photodetectors as passive or active photodiode circuits, as photogate circuits, as logarithmic sensor pixel circuits, or as charge-modulation devices. Some embodiments also implement the photodetectors as smaller-than-conventional photodetectors, that is, photodetectors having photo-sensing elements smaller than conventional elements.

Brief Description of the Drawings

Figure 1 is a block diagram of an exemplary imaging array 100 incorporating the invention.

Figure 2 is a block diagram of an exemplary group-pixel circuit 200 incorporating the present invention.

Figure 3 is a block diagram of an exemplary pixel circuit 300.

Description of the Preferred Embodiments

The following detailed description, which references and incorporates Figures 1-3, describes and illustrates one or more specific embodiments of the invention. These embodiments, offered not to limit but only to exemplify and teach, are shown and described in sufficient detail to enable those skilled in the art to implement or practice the invention. Thus, where appropriate to avoid obscuring the invention, the description may omit certain information known to those of skill in the art.

Figure 1 shows an exemplary imaging array 100 incorporating teachings of the present invention. Imaging array 100 includes group pixels 110, 112, 114, and 116, an address line 120, a drain line 130, a reset line 140, and a signal line 150. for controlling the group pixels. (For clarity, the figure omits conventional features, such as row-select logic, column-select logic, timing-and-control circuitry, and analog-to-digital converters.) In the exemplary embodiment, array 100 includes four group pixels; however, other embodiments include 256x256 arrays, 512x512 arrays, 1024x1024 arrays. Still larger arrays are also within the scope of the invention.

Each of group pixels 110-116 includes two or more photodetectors, or sensor pixels. Group pixel 110 includes sensor pixels 110a, 110b, 110c, and 110d, and group pixels 112, 114, and 116 include respective sensor pixels 112a-112d, 114a-114d, and 116a-116d. Lines 120, 130, and 140, in the exemplary embodiment, control the group pixel in accord with known techniques for addressing and controlling conventional sensor pixels in imaging arrays. In some embodiments, each group pixels provides a particular output color, such as red, blue, or green.

Figure 2 shows a block diagram of an exemplary group-pixel circuit 200 applicable to each of group pixels 110-116 in Figure 1. Circuit 200 includes N sensor pixels, of which sensor pixels 202, 204, 206, and 208 are representative, a summer 210, a variable-gain amplifier 212, and an automatic gain controller 214. The N pixels 202-206, which operate according to known principles, are coupled to an input of summer 208, either through direct connection or through a multiplexer

(not shown). Some embodiments include one or more analog-to-digital converters coupled between the signal lines of the pixels and the summer, depending on whether summer 210 is analog or digital.

Summer 210 aggregates the N responses of the N pixels 202-206 and outputs a first aggregate or group image signal to amplifier 212. (Some embodiments include in analog-to-digital converter between the summer and the amplifier.) Amplifier 212, which in some embodiments is analog and in others is digital, amplifies or scales the first group image signal and outputs a second group image signal to automatic gain controller 214 as well as to conventional imaging processing and display circuitry (not shown.) See U.S. Patent 5,854,655, which is incorporated herein by reference.

Automatic gain controller 214, which is analog or digital, compares the second group image signal to an analog or digital reference current or voltage. If the comparison indicates that the second group image signal differs from the reference, controller 212 proportionately changes, that is, increases or decreases, the gain of amplifier 210, assuming that one or more of the N pixels or related interconnective circuitry is faulty. In the exemplary embodiment, gain controller 214 sets the gain to a factor proportional to the ratio of N, the number of pixels comprising the group pixel to M, the number of correctly operating or non-faulty pixels in the group pixel.

To determine the number of non-faulty pixels, some embodiments, check the performance of each pixel in each group pixel as a start-up diagnostic test and maintain a record of the number of faulty or non-faulty pixels in each group pixel. Other embodiments dynamically or periodically determine a difference between the first aggregate image signal and a reference, and then determine from the difference how many pixels are faulty. The reference in some embodiments is based on a factory test image.

Figure 3 shows an exemplary sensor pixel circuit 300 applicable to each of the pixels in Figures 1 and 2. Circuit 300, a photodiode-type active sensor pixel circuit, includes photodiode 310, a source-follower field-effect transistor SF, a row-select field-effect transistor SL, and a charge-reset field-effect transistor RS. (An n-

channel load transistor for source-follower transistor SF is not shown.) Each field-effect transistor has respective gate, drain, and source nodes. The circuit further includes an address line 320, a drain line 330, a reset line 340, and a signal line 350.

In operation, a voltage develops across photodiode 310 based on incident light. Application of appropriate control signals on the gate of transistor SL produces an image signal on signal line 350 based on the voltage across the photodiode. Signal line 350 couples the image signal to an input node of an analog-to-digital converter or summer, such as summer 210 in Figure 2.

Various embodiments implement the photodetectors as passive or active photodiode circuits, as photogate circuits, as logarithmic sensor pixel circuits, or as charge-modulation devices. (See, for example, Eric R. Fossum, CMOS Image Sensors: Electronic Camera-On-A-Chip, 1995 International Electron Devices Meeting Digest of Technical Papers, which is incorporated herein by reference.) Some embodiments each photodetector occupies a surface area less than 30 square microns, such as 15 or 25 square microns. Some of these embodiments have a fill factor greater than 30 percent. Thus, the present invention is not limited to any particular photodetector circuit or class of photodetector circuits.

Conclusion

In furtherance of the art, the inventors have presented new imaging arrays and related methods for compensating for defective photodetectors. One exemplary embodiment of a new imaging array includes one or more group pixel circuits, each of which comprises two or more photodetectors that are substantially smaller than conventional photodetectors, for example about 15 or 25 square microns. Each group pixel circuit produces a single group image signal. The group image signal is then scaled or amplified to compensate for defective or malfunctioning photodetectors.

The embodiments described above are intended only to illustrate and teach one or more ways of practicing or implementing the present invention, not to restrict its breadth or scope. The scope of the invention intended to encompass all ways of

practicing or implementing the principles of the invention, is defined only by the following claims and their equivalents.

Claims

1. An imaging system comprising:

a group pixel comprising two or more photodetectors for providing two or more corresponding pixel image signals; and

a summer coupled to each of the two or more photodetectors for outputting an aggregate image signal based on the two or more corresponding pixel image signals.

2. The imaging system of claim 1 wherein the summer comprises an analog-to-digital converter.

3. An imaging system comprising:

a group pixel comprising two or more photodetector circuits for providing two or more corresponding pixel image signals, with each photodetector circuit having a photodiode and occupying a surface area less than 50 square microns; and

a summer coupled to each of the two or more photodetectors for outputting an aggregate image signal based on the two or more corresponding pixel image signals.

4. The imaging system of claim 3 wherein the summer comprises an analog-to-digital converter.

5. An imaging system comprising:

a group pixel comprising two or more photodetector circuits for providing two or more corresponding pixel image signals, with each photodetector circuit occupying a surface area less than 30 square microns and comprising:

a source-follower transistor have a gate, source, and drain;

a ground node; and

a photodiode coupled between the gate of the source-follower transistor and the ground node; and

a summer coupled to each of the two or more photodetectors for outputting an aggregate image signal based on the two or more corresponding pixel image signals.

6. The imaging system of claim 5 wherein the summer comprises an analog-to-digital converter.

7. An imaging system comprising:

a group pixel comprising two or more photodetectors for providing two or more corresponding pixel image signals;

a summer responsive to the two or more corresponding pixel image signals for outputting an aggregate image signal;

a variable-gain amplifier responsive to the aggregate image signal for outputting an amplified aggregate image signal based on an adjustable amplifier gain; and

an automatic gain controller for adjusting the adjustable amplifier gain based on the aggregate image signal.

8. The imaging system of claim 7 wherein the summer comprises an analog-to-digital converter.

9. The imaging system of claim 7 wherein the variable-gain amplifier is a digital amplifier.

10. An imaging system comprising:

a group pixel comprising two or more photodetectors for providing two or more corresponding pixel image signals;

a summer responsive to the two or more corresponding pixel image signals for outputting an aggregate image signal;

a variable-gain amplifier responsive to the aggregate image signal for outputting an amplified aggregate image signal based on an adjustable amplifier gain; and

an automatic gain controller for adjusting the adjustable amplifier gain based on the amplified aggregate image signal.

11. The imaging system of claim 10 wherein the summer comprises an analog-to-digital converter.

12. The imaging system of claim 10 wherein the variable-gain amplifier is a digital amplifier.

13. An imaging system comprising:

two or more group pixels comprising two or more photodetector circuits for providing two or more corresponding pixel image signals, with each photodetector circuit having a surface area less than 50 square microns and comprising:

a source-follower transistor have a gate, source, and drain;

a ground node; and

a photodiode coupled between the gate of the source-follower transistor and the ground node;

a summer responsive to two or more of the corresponding pixel image signals for outputting an aggregate image signal;

a variable-gain amplifier responsive to the aggregate image signal for outputting an amplified aggregate image signal based on an adjustable amplifier gain; and

an automatic gain controller for adjusting the adjustable amplifier gain based on the aggregate image signal.

14. The imaging system of claim 13 wherein the summer comprises an analog-to-digital converter.

15. The imaging system of claim 13 wherein the variable-gain amplifier is a digital amplifier.

16. An imaging system comprising:

two or more group pixels comprising two or more photodetector circuits for providing two or more corresponding pixel image signals, with each photodetector circuit having a surface area less than 50 square microns and comprising:

a source-follower transistor have a gate, source, and drain;

a ground node; and

a photodiode coupled between the gate of the source-follower transistor and the ground node;

a summer responsive to two or more of the corresponding pixel image signals for outputting an aggregate image signal;

a variable-gain amplifier responsive to the aggregate image signal for outputting an amplified aggregate image signal based on an adjustable amplifier gain; and

an automatic gain controller for adjusting the adjustable amplifier gain based on the amplified aggregate image signal.

17. The imaging system of claim 16 wherein the summer comprises an analog-to-digital converter.

18. The imaging system of claim 16 wherein the variable-gain amplifier is a digital amplifier.

19. An imaging system comprising:

two or more group pixels comprising two or more photodetector circuits for providing two or more corresponding pixel image signals, with each photodetector circuit having a surface area less than 50 square microns and comprising:

a source-follower transistor have a gate, source, and drain;

a ground node; and

a photodiode coupled between the gate of the source-follower transistor and the ground node;

a summer having an output responsive to two or more of the corresponding pixel image signals for outputting an aggregate image signal;

a variable-gain amplifier having an input, an output, and a gain-control terminal, with the input operatively coupled to the output of the summer;

an automatic gain controller having an input coupled to the output of the variable-gain amplifier and having an output operatively coupled to the gain-control terminal of the variable-gain amplifier.

20. The imaging system of claim 19 wherein the summer comprises an analog-to-digital converter.

21. The imaging system of claim 19 wherein the variable-gain amplifier is a digital amplifier.

22. A method for compensating for defective or malfunctioning photodetectors in an imaging array, comprising:

aggregating two or more image signals to define an aggregate image signal;

comparing the aggregate image signal to a reference; and

amplifying the aggregate image signal based on results of comparing the aggregate image signal to the reference.

23. A method comprising:

aggregating two or more image signals to define an aggregate image signal; and

determining a number of defective or non-defective pixels based on the aggregate image signal.

24. A method comprising:

aggregating two or more image signals to define an aggregate image signal;

determining a number of defective or non-defective pixels based on the aggregate image signal; and

amplifying the aggregate image signal based on the determined number of defective or non-defective pixels.

25. A method comprising:

means for aggregating two or more image signals to define an aggregate image signal;

means for determining a number of defective or non-defective pixels based on the aggregate image signal; and

means for amplifying the aggregate image signal based on the determined number of defective or non-defective pixels.

26. An image system comprising:

means for aggregating two or more image signals to define an aggregate image signal; and

means for determining a number of defective or non-defective pixels based on the aggregate image signal.

27. A method comprising:

means for aggregating two or more image signals to define an aggregate image signal;

means for determining a number of defective or non-defective pixels based on the aggregate image signal; and

means for amplifying the aggregate image signal based on the determined number of defective or non-defective pixels.

Abstract of the Disclosure

Imaging arrays are electronic devices that sense light and output electrical signals representative of the sensed light. An imaging array comprises thousands or millions of photodetectors that convert sensed light into corresponding electric signals, which are ultimately converted into digital image signals for recording or viewing. One problem with conventional imaging arrays concerns defective or malfunctioning photodetectors. Defective photodetectors typically result in erroneous image signals that ultimately degrade the quality of resulting images. Accordingly, the present inventors devised new imaging arrays including redundant photodetectors to compensate for defective photodetectors. One exemplary embodiment includes one or more photodetectors that are substantially smaller than conventional photodetectors, for example about 10 or 25 square microns. The smaller-than-conventional photodetectors are arranged into two or more groups, with each group having two or more photodetectors coupled to produce a single group image signal. If the group image signal for a group falls below some threshold level indicative of a defective or malfunctioning photodetector, the group image signal is amplified to compensate for the loss.

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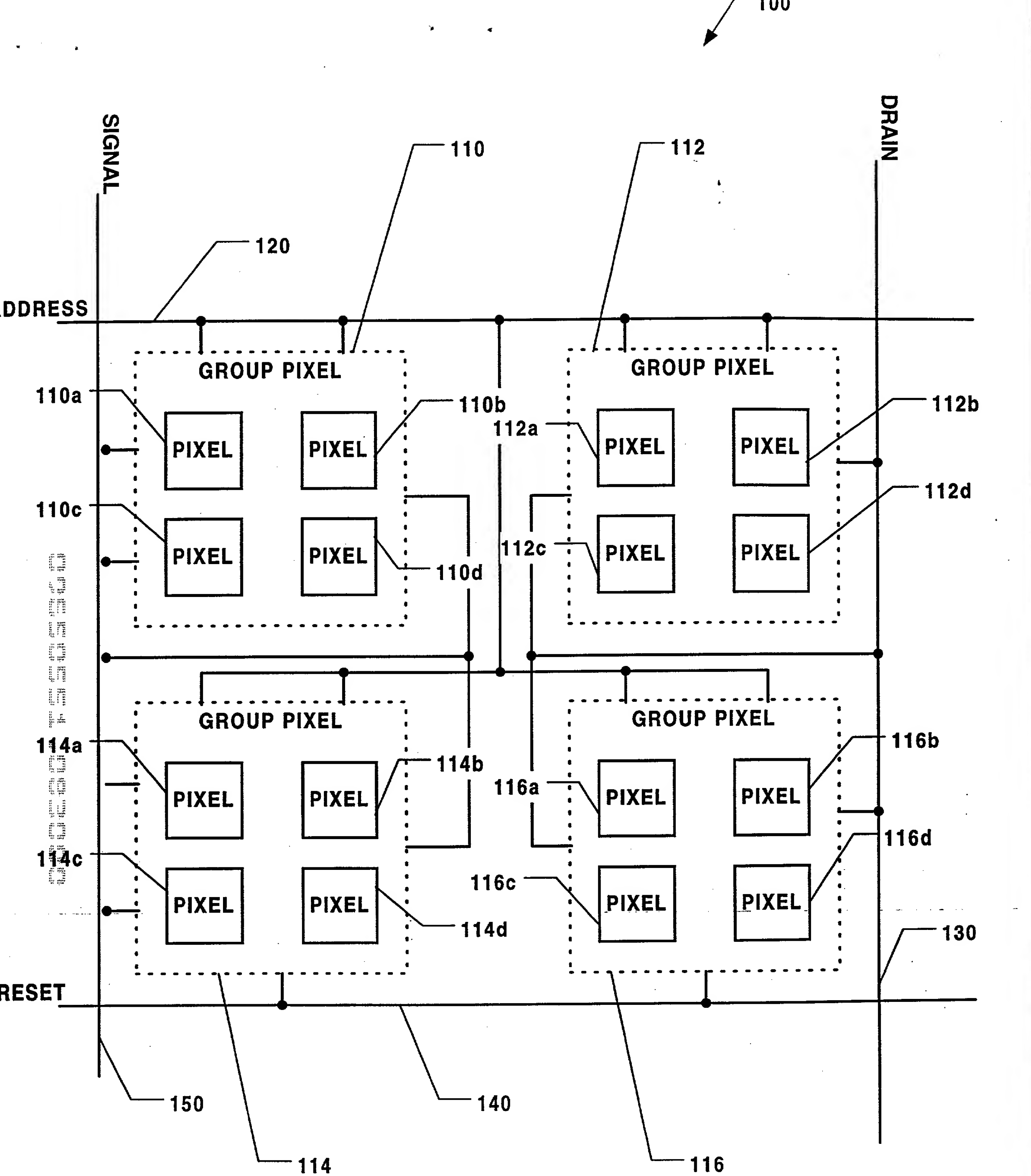
100
SIGNAL
DRAIN
110
112
120
ADDRESS
GROUP PIXEL
GROUP PIXEL
110a
PIXEL
PIXEL
110b
112a
PIXEL
PIXEL
112b
110c
PIXEL
PIXEL
110d
112c
PIXEL
PIXEL
112d
GROUP PIXEL
GROUP PIXEL
114a
PIXEL
PIXEL
114b
116a
PIXEL
PIXEL
116b
116d
114c
PIXEL
PIXEL
114d
116c
PIXEL
PIXEL
130
RESET
150
140
114
116

FIGURE 1

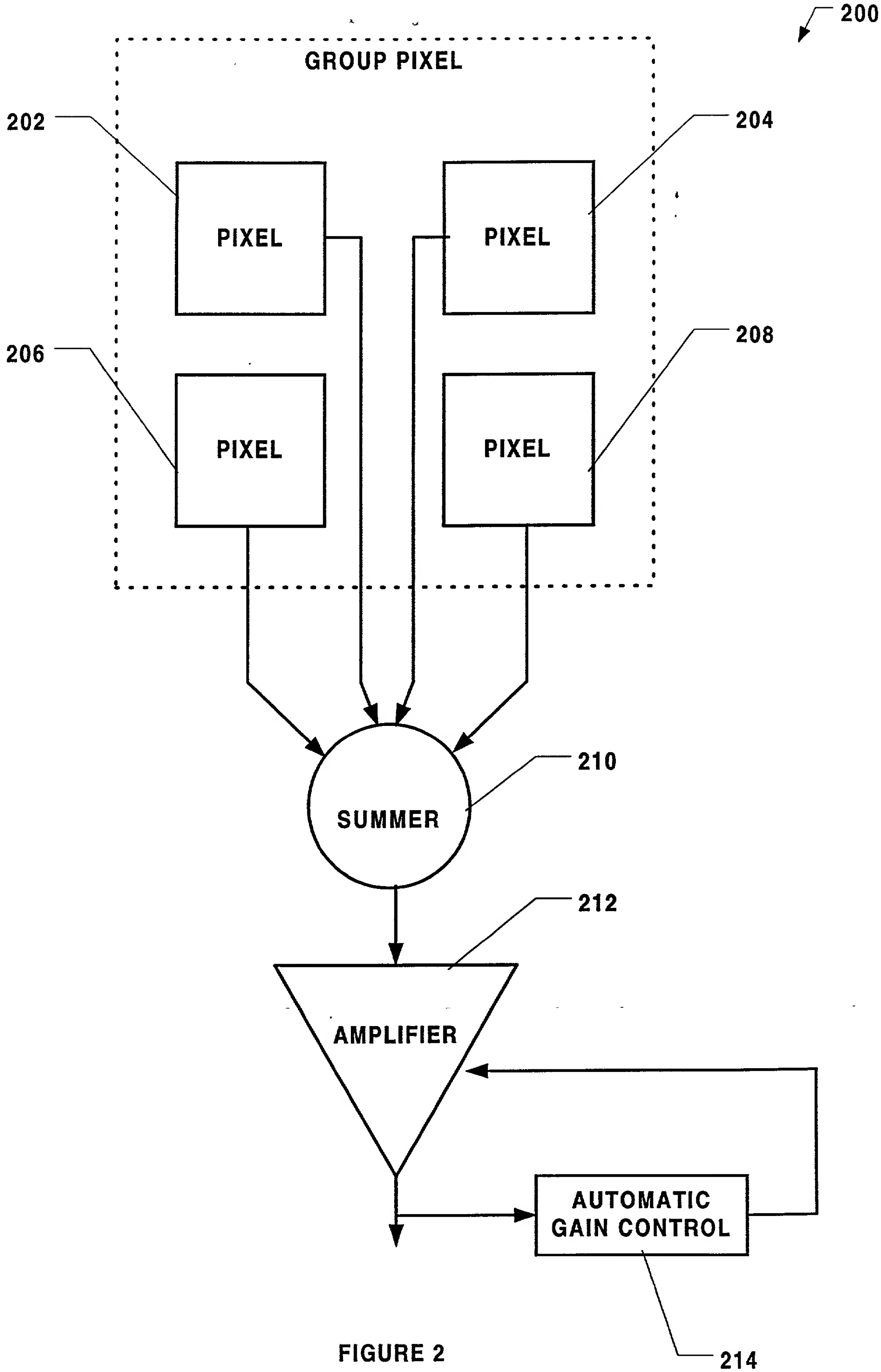
200
GROUP PIXEL
202
204
PIXEL
PIXEL
206
208
PIXEL
PIXEL
210
SUMMER
212
AMPLIFIER
AUTOMATIC
GAIN CONTROL
214

FIGURE 2

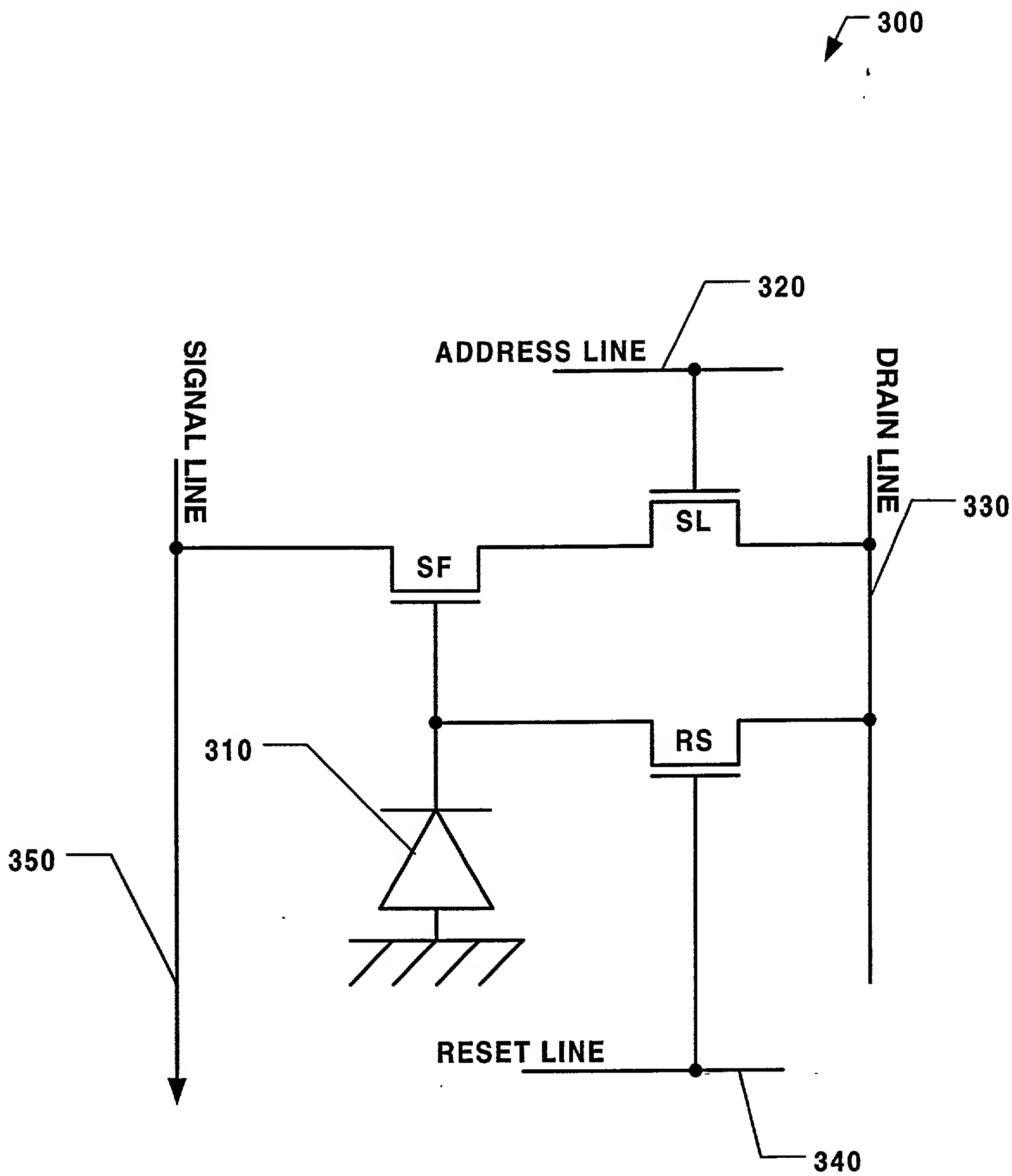
300
320
ADDRESS LINE
SIGNAL LINE
DRAIN LINE
330
SL
SF
RS
310
350
RESET LINE
340

FIGURE 3

SCHWEGMAN ■ LUNDBERG ■ WOESSNER ■ KLUTH

United States Patent Application

COMBINED DECLARATION AND POWER OF ATTORNEY

As a below named inventor I hereby declare that: my residence, post office address and citizenship are as stated below next to my name; that

I verily believe I am the original, first and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled: **REDUNDANT IMAGING METHODS AND SYSTEMS**.

The specification of which is attached hereto.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with 37 C.F.R. § 1.56 (attached hereto). I also acknowledge my duty to disclose all information known to be material to patentability which became available between a filing date of a prior application and the national or PCT international filing date in the event this is a Continuation-In-Part application in accordance with 37 C.F.R. §1.63(e).

I hereby claim foreign priority benefits under 35 U.S.C. §119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on the basis of which priority is claimed:

No such claim for priority is being made at this time.

I hereby claim the benefit under 35 U.S.C. § 119(e) of any United States provisional application(s) listed below:

No such claim for priority is being made at this time.

I hereby claim the benefit under 35 U.S.C. § 120 or 365(c) of any United States and PCT international application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT international application in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose material information as defined in 37 C.F.R. § 1.56(a) which became available between the filing date of the prior application and the national or PCT international filing date of this application:

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I hereby appoint the following attorney(s) and/or patent agent(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected herewith:

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Clark, Barbara J.	Reg. No. 38,107	Lundberg, Steven W.	Reg. No. 30,568	Schwegman, Micheal L.	Reg. No. 25,816
Clise, Timothy B.	Reg. No. 40,957	Lynch, Michael L.	Reg. No. 30,871	Scott, John C.	Reg. No. 38,613
Dahl, John M.	Reg. No. 44,639	Maeyaert, Paul L.	Reg. No. 40,076	Smith, Michael G.	Reg. No. 45,368
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Gamon, Owen J.	Reg. No. 36,143	Moore, Charles L., Jr.	Reg. No. 33,742	Viksnins, Ann S.	Reg. No. 37,748
Harris, Robert J.	Reg. No. 37,346	Nama, Kash	Reg. No. 44,255	Woessner, Warren D.	Reg. No. 30,440
Huebsch, Joseph C.	Reg. No. 42,673	Nelson, Albin J.	Reg. No. 28,650		

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Signature: ______________________ Date: ______________
Eugene H. Cloud

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(a) A patent by its very nature is affected with a public interest. The public interest is best served, and the most effective patent examination occurs when, at the time an application is being examined, the Office is aware of and evaluates the teachings of all information material to patentability. Each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability as defined in this section. The duty to disclose information exists with respect to each pending claim until the claim is canceled or withdrawn from consideration, or the application becomes abandoned. Information material to the patentability of a claim that is canceled or withdrawn from consideration need not be submitted if the information is not material to the patentability of any claim remaining under consideration in the application. There is no duty to submit information which is not material to the patentability of any existing claim. The duty to disclose all information known to be material to patentability is deemed to be satisfied if all information known to be material to patentability of any claim issued in a patent was cited by the Office or submitted to the Office in the manner prescribed by §§ 1.97(b)-(d) and 1.98. However, no patent will be granted on an application in connection with which fraud on the Office was practiced or attempted or the duty of disclosure was violated through bad faith or intentional misconduct. The Office encourages applicants to carefully examine:

(1) prior art cited in search reports of a foreign patent office in a counterpart application, and

(2) the closest information over which individuals associated with the filing or prosecution of a patent application believe any pending claim patentably defines, to make sure that any material information contained therein is disclosed to the Office.

(b) Under this section, information is material to patentability when it is not cumulative to information already of record or being made of record in the application, and

(1) It establishes, by itself or in combination with other information, a prima facie case of unpatentability of a claim; or

(2) It refutes, or is inconsistent with, a position the applicant takes in:

(i) Opposing an argument of unpatentability relied on by the Office, or

(ii) Asserting an argument of patentability.

A prima facie case of unpatentability is established when the information compels a conclusion that a claim is unpatentable under the preponderance of evidence, burden-of-proof standard, giving each term in the claim its broadest reasonable construction consistent with the specification, and before any consideration is given to evidence which may be submitted in an attempt to establish a contrary conclusion of patentability.

(c) Individuals associated with the filing or prosecution of a patent application within the meaning of this section are:

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